

Spaceport Performance Measures

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Spaceports have traditionally been characterized by performance measures associated with their site characteristics. Measures such as "Latitude" (proximity to the equator), "Azimuth" (range of available launch azimuths) and "Weather" (days of favorable weather) are commonly used to characterize a particular spaceport. However, other spaceport performance measures may now be of greater value. These measures can provide insight into areas of operational differences between competing spaceports and identify areas for improving the performance of spaceports. This paper suggests Figures of Merit (FOMs) for spaceport "Capacity" (number of potential launch opportunities per year and / or potential mass to low earth orbit (LEO) per year); "Throughput" (actual mass to orbit per year compared to capacity); "Productivity" (labor effort hours per unit mass to orbit); "Energy Efficiency" (joules expended at spaceport per unit mass to orbit); "Carbon Footprint" (tons CO₂ per unit mass to orbit). Additional FOMs are investigated with regards to those areas of special interest to commercial launch operators, such as "Assignment Schedule" (days required for a binding assignment of a launch site from the spaceport); "Approval Schedule" (days to complete a range safety assessment leading to an approval or disapproval of a launch vehicle); "Affordability" (cost for a spaceport to assess a new launch vehicle); "Launch Affordability" (fixed range costs per launch); "Reconfigure Time" (hours to reconfigure the range from one vehicle's launch ready configuration to another vehicle's configuration); "Turn Around Time" (minimum range hours required between launches of an identical type launch vehicle). Available or notional data is analyzed for the KSC/CCAFS area and other spaceports. Observations regarding progress over the past few decades are made. Areas where improvement are needed or indicated are suggested.

I. Introduction – Why Measure Spaceport Performance?

For many years spaceport development in the United States was controlled exclusively by the Federal Government. In the 1990s several commercial spaceports were developed to support commercial orbital launches. At that time most of these commercial spaceports were based on a cooperative State-Federal system. They were still located on Federal property, such as the California Spaceport located on Vandenberg Air Force Base. Spaceport development has continued to evolve.¹ As of writing this paper there are seven "commercial" spaceports with an active license issued by the Federal Aviation Administration's Office of Commercial Space Transportation (FAA/AST). Of these spaceports three evolved from Federal ranges and are hybrid State-Federal spaceports, three evolved from traditional airfields *aerospaceports*², and one is an independent spaceport built on a new site from the ground up.³ Today launch operators have at least some choice of where they can launch vehicles of limited capability. The public is given choices regarding local tax options to fund new spaceport development. Aerospace authorities continue to assess demand for a spaceport in their area. We must identify the indicators for each stakeholder as they each decide their operational, management, and financial performance strategies. By so doing, the space transportation industry can grow beyond the small-scale commercial operations that exist today and begin opening-up space for larger segments of the economy, and someday, for us all.

Spaceports have several characteristics which are substantially invariant. These need not be measured and evaluated every year. Geographical characteristics such as longitude, latitude and available launch azimuths are

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topics which spaceports are unlikely to change. Meteorological conditions vary, but are substantially characterized and not manageable. These topics are normally accounted for and addressed by spaceport architects in coordination with flight systems designers and may be cataloged once and updated as required.

How do we meaningfully compare spaceport capabilities and performance? A few attempts have been made to evaluate spaceport performance. Quite often spaceport siting issues have evolved around the perceived performance needs of the launch vehicle. For example, taking full advantage of the Earth's rotation for payload lift performance per flight, system operators often desire spaceports located near the Equator. However, measures such as this do not necessarily address requirements of all the major stakeholders. Figure 1 shows, for example, the lack of correlation between total payloads delivered from the world's spaceports in the last ten years (2000 through 2009).

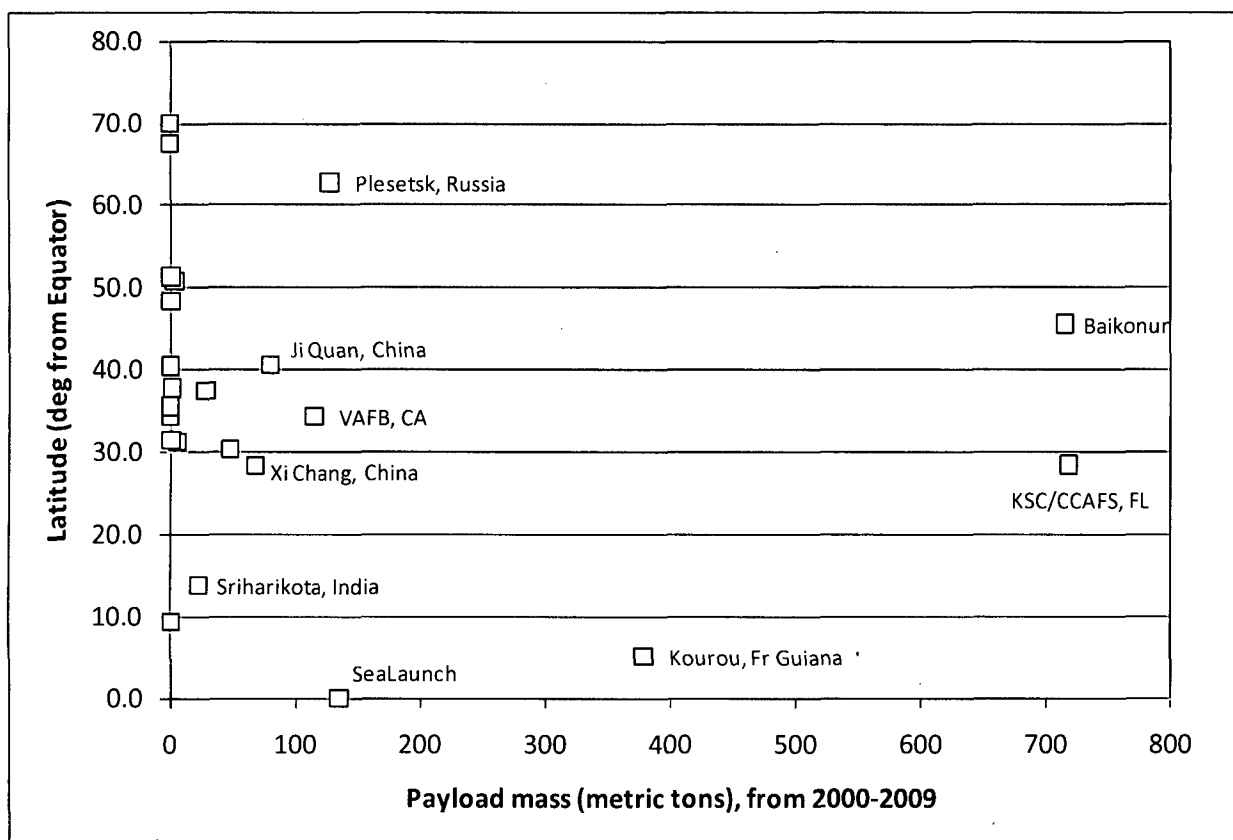


Figure 1—Spaceport Payload Delivery by Latitude from 2000-2009.

The major stakeholders of spaceports are the space flight “User-Operators” (commercial launch operators and government launch/landing operators), the flying “Customer,” the “Owners-Operators” of the Spaceport, and the “Public.” The meaningful performance measurements are those which vary year-to-year, and are valued by these stakeholders.

Therefore, we measure *spaceport performance* in order to capture the topics which vary from year-to-year, and are of high interest to the stakeholders.

II. Stakeholder Performance Interests

“Space Flight Service Operators” use a spaceport to quickly and inexpensively launch their vehicles on-time into space. These users are like airlines operating at airports. Therefore, the space flight operators at the Spaceport seek a sufficiently high enough *throughput* to meet the needs of their business; a high degree of system *availability* and *responsiveness* (for pad assignments, vehicle evaluations, and range turn around, with ample launch opportunities); *safety*; *financial* return (sufficiently low launch costs to allow a profit, and with sufficiently

understood launch costs to allow predictable budgeting); and *energy efficiency/environmentally sustainable* practices, for long-term business viability.

“Spaceport Authority/Operators” want a Spaceport which generates healthy, stable growth in space flight traffic and resulting revenue. Therefore “Spaceport Authorities” and their “Spaceport Operators” (i.e., the contracted operators of the spaceport infrastructure—not to be confused with space flight service operators who act as a “taxi service” or, “spaceline”) seek steady, stable *throughput growth*. This throughput growth is capacity which is highly utilized, but always with room to grow in both productivity (i.e., efficiency), and overall productiveness. It values attracting high quality operators (both of the spaceport infrastructure, and the tenant flight service providers), and in providing their tenants and customers the spaceport capabilities they need to thrive. For example, spaceports need to make ample launch opportunities available to its operators, provide inherent *safety* for the ground crews, space flight vehicles, and the surrounding population potentially, all impacted from safety issues of many different kinds. As such, spaceports and their user-operator community are concerned with compliance measures and institutions charged with ensuring the spaceworthiness of its flight and ground equipment, personnel, and management systems, for example. The Spaceport Authority and its operators are also concerned with *financial* return (net revenue sufficient to return to stock or bondholders) and *sustainable* practices (for long-term business viability)

The “Public” wants a Spaceport which provides employment, technological progress and enhances national prestige. Therefore, “Public” the seeks visible evidence of space flight activity with regularly occurring launches that generate information which become news events, or experiences become accessible to the average citizen. They must, therefore proved accurate *schedule information* for launch viewing and reservations at nearby, or on-site, accommodations. The Public is also looking for public safety in general *safety*. The Public is also concerned with obtaining, *financial* return, i.e., sufficient local development and tax revenue to provide for any public investment). Finally, it is concerned with *sustainable* practices and environmental safety (for long-term planetary viability.)

In response to these stakeholders, the authors suggest that a Spaceport Performance Measurement system should indicate and measure specific topics in the following broad categories:

- *Throughput*: What is the capacity of the Spaceport and how busy is it?
- *Availability/Responsiveness*: How many launch attempts are available / year?
- *Safety*: Does the safety performance of a vehicle and ground systems vary from Spaceport to Spaceport? If so what can be done to improve the safety performance of Spaceports in general.
- *Financial*: affordability and performance
- *Sustainability*: environmental and energy efficiency practices and performance
- *Geographical*: advantages, limitations and performance (azimuths, flight corridors, weather – benchmark and catalog)

Table 1—Types and characteristics of Spaceport Stakeholder by Business Sector

Spaceport Stakeholder/Space Sector	Civil	Commercial	Military
Space Flight Customer Cargo/passengers who depart from, or arrive at, a spaceport to begin or end a spacelflight	<u>Assured Delivery</u> <i>Example</i> : NASA JPL/JHU New Horizons/Pluto	<u>Low-Cost, On-Time, Dependable Delivery</u> <i>Example</i> : Echostar/Teledesic	<u>Assured Delivery</u> <i>Example</i> : USAF GPS <u>Fast Call-up Delivery</u> <i>Example</i> : ORS Program
Space Flight Service Operator Owns and/or operates flight and ground equipment to produce space flights	<u>Mission Assurance</u> Fly Safely, Meet the Manifest <i>Example</i> : NASA Shuttle Pgm	<u>On-Time, Low-Cost Scheduled Delivery</u> Simple Ops, Low Equip Costs, Highly dependable, profitable	<u>Mission Assurance</u> Fly Safely, Meet the Manifest <i>Example</i> : NASA Shuttle Pgm
Spaceport Authority/Operator Owns and/or operates spaceport assets needed to support Space Flight Customers and Space Flight Service Operators	<u>Multiple Mission/Program Support</u> <i>Example</i> : NASA Kennedy Space Center	<u>Multiple Customer/Business Support</u> <i>Example</i> : ESA Kourou	<u>Multiple Mission/Program Support</u> <i>Example</i> : Vandenberg AFB
Public Public stakeholders interested in economic, environmental, and other impacts (local, state, federal and global)	<u>Attractive for Civilian Government Contracts</u>	<u>Attractive for Commercial Business Growth</u>	<u>Attractive for Military Government Contracts</u>

A. Throughput Capacity

Capacity is a measure of the ability of the Spaceport to accommodate a range of operators using their flight equipment of varying vehicle or payload sizes. The stakeholders would use *capacity* to evaluate the ability to accommodate a space flight operator's business needs. Likewise, the spaceport architect examines the capacity of the facilities to accommodate the needs of multiple operators. Potential indicators of capacity would be:

- Spaceport Line Capacity (Flights/year/line): Number of available launch attempts / year of a single string (or "line") of processing stations required to produce a space flight at the spaceport. For example, the line capacity of a single Space Shuttle Orbiter flowing through a single set of ground facilities is about 2.7 flights per year.
- Spaceport System Capacity (Flights/year/system): Number of available launch attempts / year of a system with multiple (or parallel) processing stations simultaneously producing space flights a launch at the Spaceport. For example, the capacity of Space Shuttle Orbiter Fleet flowing through all of the available ground facilities during the late 1990s was about seven (7) to eight (8) flights per year. (Note: for many contemporary systems, the spaceport *line capacity* and *system capacity* are the same since the system design only possesses a single string of assets; e.g., the Atlas V system at Cape Canaveral and at Vandenberg AFB has only one vehicle assembly and launch pad.
- Spaceport Operator Capacity (Number of Separate System Operators/Programs): Number of individual launch systems/programs which can be accommodated.
- Spaceport Sizing Capacity/Limit (NEW): Largest vehicle accommodated at the Spaceport, based on explosive Net Equivalent Weight (NEW)
- Total Spaceport Output Capacity (kg to LEO): Total potential tonnage which could be launched to LEO / year.

Load Factor is an indicator of what portion of the *capacity* is utilized by the space flight service operator. *Load factor* indicates to the operator how much of the *capacity* is already in use, and how much is still available for new space flight business opportunities. For the spaceport authority-operator, *load factor* indicates how efficiently the tenants are providing service and how efficiently the spaceport is supporting their operations, as well as satisfying the needs of prospective space flight customers. More importantly, it is also an indicator how much revenue is being lost because it is not fully utilized. Potential indicators of *load factor* could be:

- Space Flight Load Factor: Ratio of actual (Flights/year) / System Capacity (Flights/Year/system)
- System/Program Load Factor (Programs): Ratio of actual (Number of Systems/Programs) / Capacity (Number of System/Programs)
- Spaceport Sizing Load Factor (NEW): Ratio of actual largest (NEW) / Sizing Capacity/Limit (NEW)
- Total Spaceport Load Factor (kg to LEO): Ratio of actual (metric tons delivered to space per year) / Total Spaceport Capacity (metric tons delivered to space per year)

B. Availability/Responsiveness

The Spaceport must commit and provide operational infrastructure on a schedule which is *responsive* to the business plan needs of the space flight operator and *available* when the customer demands access to space. The schedule must allow the user to fly on desired dates/times without a concern for postponement or cancellation due to other overriding flights or conflicting activities⁴:

- On-Time Ratio (Launches): Ratio of number of flights which launch on the day first announced to the number of flights that year.
- Range Reconfigure Time (Hours): Amount of time the spaceport's range is required to reconfigure their systems to accommodate a different flight vehicle.
- Facility Assignment Schedule (Days): Number of days from time of application for a spaceport facility until signed commitment.
- Vehicle Assessment/Disposition Schedule (Days): Number of days from time of application for a new vehicle until signed as "approved" or "denied".

Delays may be caused by a variety of circumstances. Many delays occur because the vehicle, or the payload (or both) are not ready. They can also be due to the ground system, or from other operating constraints, such as weather and flight path encroachments. Regardless of source, those delays which do actually occur can be measured. Potential indicators of *delays* could be:

- Space Flight Delays (Occurrences): Number of occurrences in the past year when a scheduled flight was delayed for any reason.
- Space Flight Delay Impact (Days): Cumulative amount of serial critical time in the past year when a scheduled flight was delayed for any reason.
- Space Flight Operator Delays (Occurrences): Number of occurrences in the past year when a scheduled flight was delayed for space vehicle operator availability/anomalies.
- Space Flight Operator Delay Impact (Days): Cumulative amount of serial critical time in the past year when a scheduled flight was delayed for space vehicle operator availability/anomalies.
- Customer Delays (Occurrences): Number of occurrences in the past year when a scheduled flight was delayed for space flight customer availability/anomalies.
- Customer Delay Impact (Days): Cumulative amount of serial critical time in the past year when a scheduled flight was delayed for space flight customer availability/anomalies.
- Spaceport Equipment/Service Delays (Occurrences): Number of occurrences in the past year when a scheduled flight was delayed for spaceport equipment or service availability/anomalies.
- Spaceport Equipment/Service Delay Impact (Days): Cumulative amount of serial critical time in the past year when a scheduled flight was delayed for spaceport equipment or service availability/anomalies.
- Preemption Delay (Occurrences): Number of occurrences in the past year when a scheduled flight was preempted because of a national priority.
- Preemption Delay (Days): Cumulative amount of serial critical time in the past year when a scheduled flight was preempted because of a national priority.
- Flight Path/Airspace Availability (Hours/ year): Number of hours / year the flight path/airspace is available on an unrestricted basis for space flight operations.

C. Safety

The spaceport has a responsibility to serve the public interest by maintaining flight and ground safety, as well as public safety. Potential indicators of "Spaceport Safety" are shown in Table 2:

Table 2—Spaceport Safety Considerations

STRATEGIC SPACEPORT SAFETY MEASURES	SPACE FLIGHT SUCCESS RATIOS (i.e., track record for outbound & inbound, human and cargo space flights; Loss of Vehicle/Crew)
	IN-FLIGHT TERMINATION RATE (space flights terminated by spaceport/range per year)
	NUMBER OF GROUND PERSONNEL INJURIES/CLOSE-CALLS
	TOTAL FACILITY STANDDOWN TIME RESOLVING FLIGHT SYSTEM SAFETY ISSUES
	TOTAL FACILITY STANDDOWN TIME RESOLVING GROUND SYSTEM SAFETY ISSUES
	NUMBER OF FACILITY AND EQUIPMENT MISHAPS/CLOSE-CALLS
Spaceport Flight & Ground System Safety Objectives	EXPLOSIVE HAZARDS-Decreased Personnel and/or High-value Equipment Exposure
	CUMBUSTION/FIRE HAZARDS-Decreased Personnel and/or High-value Equipment Exposure
	TOXIC FLUID HAZARDS-Decreased Personnel and/or High-value Equipment Exposure
	CONFINED SPACE HAZARDS-Decreased Personnel and/or High-value Equipment Exposure
	INERT GAS ASPHYXIATION-Decreased Personnel and/or High-value Equipment Exposure
	HIGH PRESSURE GAS HAZARDS-Decreased Personnel and/or High-value Equipment Exposure
	HANDLING/SUSPENDED LOAD HAZARDS-Decreased Personnel and/or High-value Equipment Exposure
	ELEVATION-HEIGHT HAZARDS-Decreased Personnel and/or High-value Equipment Exposure
	FALLING OBJECT HAZARDS-Decreased Personnel and/or High-value Equipment Exposure
	ELECTRICAL HAZARDS-Decreased Personnel and/or High-value Equipment Exposure
	RADIATION HAZARDS-Decreased Personnel and/or High-value Equipment Exposure
	BIO-MEDICAL HAZARDS-Decreased Personnel and/or High-value Equipment Exposure
Spaceport Industrial/Occupational Safety Objectives	CRYOGENIC-FROSTBITE HAZARDS-Decreased Personnel and/or High-value Equipment Exposure
	OTHER MATERIAL HAZARDS (CORROSIVE, BLEACHING, ETC)-Decreased Personnel and/or High-value Equipment Exposure
	Reduced Lost-Time Injury Rate (LTIR)
	Reduced Lost Time Injury Severity Rate (LTISR)
	Reduced Maximum Work Time (MWT) Deviations
	Reduced Occupational Safety Mishaps (Type A thru D)

D. Financial/Business Case Sensitivity

The space flight service providers require spaceports to utilize a fee structure which enables them to consistently budget for, understand, and control costs to maintain global competitiveness. The fee aspects must present a good

value, or the service provider (i.e., the *spaceline*) will seek a more accommodating place to conduct business. The spaceport's fee structure must allow the entrepreneurial/commercial operator to evaluate their business case without a great deal of time and effort expended, and enable them to operate in a profitable manner.

This being the case, spaceports seeking commercial space flight operators need to be sensitive to the following primary drivers of the business case for the tenants they are attempting to attract

- 1) Investment / debt service (including ground system acquisition)
- 2) Recurring insurance/liability burden (overcoming technical risk/lack of demonstrated successes)
- 3) Recurring operations labor (flight rate variable costs)
- 4) Recurring maintenance labor (fixed annual labor costs)
- 5) Recurring component replacement and repair, consumables, and other materials costs-per-flight (non-labor variable costs)
- 6) Recurring support for component replacement and repair, consumables, and other annual costs (non-labor fixed costs)
- 7) Business operations and planning overhead
- 8) Profit
- 9) Revenue generation rate (flight rate)
- 10) On-time spaceport/range asset and service availability

It should be noted that the "fixed cost" items above need to be carefully identified spaceports and space flight service operators alike. Discrimination should be made for those fixed cost items that are common to multiple operators and those that are unique to individual operators. Those that are unique should be on the operator's business plan, while those that are common should be on the spaceport authority-operator's business case. With this in mind, Spaceports should seek to develop competitive fee structures common services. Potential financial indicators for which "user fees" might be based could include:

- Payload Weight Launch Fee (\$/pound):
- Crew/Passenger Launch Fee (\$/seat, or \$/crew)
- Space Flight Launch Fee (\$/flight)
- Space Flight Arrival/Landing Fee (\$/flight)
- Pad Assignment Fee (\$): Fee charged by the Spaceport to evaluate an application for a launch pad from submittal until signed commitment.
- Vehicle Assessment/Disposition Fee (\$): Fee charged by the spaceport to evaluate an application for a new vehicle until signed in approval or denial.
- Fee type (Fixed vs. Time & Materials): A fixed price amount is known and can be budgeted and limits liability. A variable, time & materials cost basis is more difficult to control and presents more cost risk.

The Spaceport Owners may seek to maximize revenue in order to create value for their shareholders or constituents. Their financial indicators would emphasize the revenue perspective:

- Spaceport Revenue Ratios (\$/\$): Ratios relating actual annual revenue to theoretical revenue, based on various Capacity (Flights) measures to various Fees (\$/Flight), for example.

E. Energy Efficiency/Environmental Sustainability

Spaceports must be inherently efficient in converting energy into space flights while being environmentally sustainable; thus contributing to the overall sustainability of the nation and the globe. For government-related facilities, executive orders (such as EO 13514) and other established regulations will contribute to implementing sustainable construction practices, set goals, and enforce those goals (e.g., certification in the global Leadership in Energy and Environmental Design program, or LEED certification). Non-federal spaceports may increasingly be evaluated, as well, for their responsibility in this area. Therefore, some potentially important overall measures could be:

- Spaceport Delivery Efficiency (joules/pound): The total amount of all energy consumed at the Spaceport / the total pounds successfully delivered into space in a given year.
- Greenhouse Gases (GHG) Discharge Efficiency (GHG pounds/pound): The total equivalent Greenhouse Gas (GHG) weight of all GHG produced at the Spaceport / the total pounds successfully delivered into space in a given year.
- Spaceport Cleanliness Factor (waste pounds/pound): The total weight of all waste products disposed of at the Spaceport / the total pounds successfully delivered to orbit in a given year.

III. Prior Work Addressing Spaceport Performance

Prior attempts to quantify Spaceport performance have presented interesting and useful background data to this discussion:

A. Business Capture Analyses

Work in 2006 evaluated Spaceport performance on a overall basis by assessing the ability of custom designed (“commercial”) Spaceports to capture their intended market⁵. The results indicated that of 13 potential launch operators which these Spaceports were intended to capture, more than half chose to launch from another location. Two operators chose to launch from a new Greenfield site, to be developed at their own expense. These results indicate that Spaceport performance is generally unsatisfactory for most of the new, entrepreneurial launch providers, but it doesn’t address the reasons for the poor performance⁶.

Entrepreneurial Vehicle	Selected “First to the Market” Spaceports ?	Selected alternative or privately developed Spaceport ?
Athena – West Coast		SLC-6
East Coast	SLC-46	
Minotaur – West Coast	SLC-8	
East Coast	Pad-0B	
Taurus		SLC-576E
Spaceship One		Mojave Air & Spaceport
Virgin Galactic		Various
Falcon Family (SpaceX)		Kwajalein / SLC-3W / SLC-40
Rocketplane		Spaceport Oklahoma
K-1		Woomera
New Sheppard (Blue Origin)		Private Spaceport
<i>Capture Rate</i>	3 of 13	10 of 13

Figure 2: 2006 Spaceport Business Capture Analysis

B. Spaceport Master Planning

The 2010 Spaceport Master Plan⁷, developed by RS&H for Space Florida included application of the “Spaceport Evaluation Mechanism” (SEM) and a “Launch Site Viability Evaluation” (LSVE).

The SEM⁸ is a tool which identifies a qualitative assessment of Spaceports in nearly 60 topics relating to business, regulatory, infrastructure, location-community-environment, human spaceflight, and cargo-satellite operations. The SEM is a readiness evaluation methodology for Spaceports. Its topic areas are not numerically measured, but are judged “Sufficiently Fulfilled”, “Insufficiently Fulfilled” or somewhere in between. Because this tool is qualitative it does not lend itself to measuring the performance of operating Spaceports.

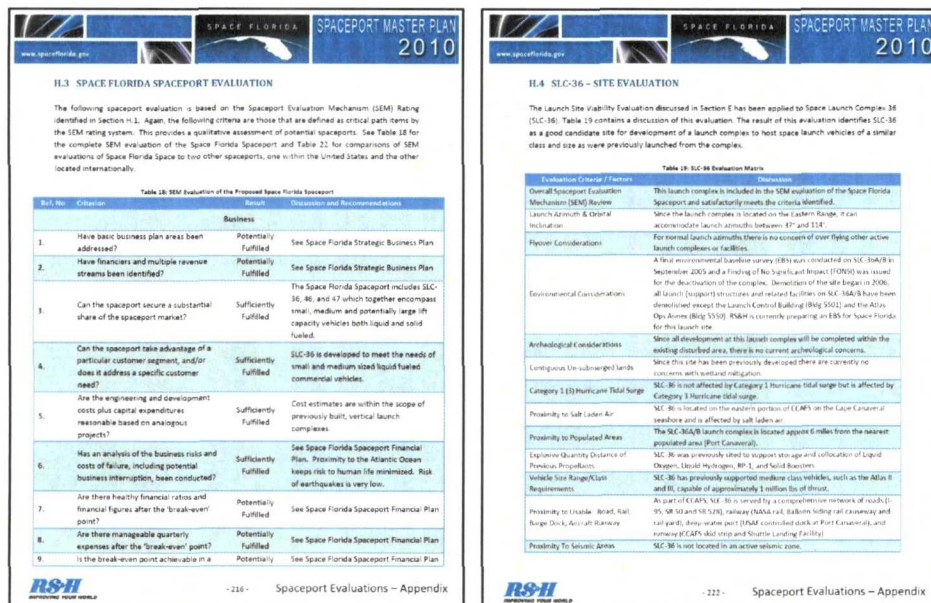


Figure 3: (L) Spaceport Evaluation Mechanism; (R) Launch Site Viability Evaluation

The second evaluation method used by the authors was a Launch Site Viability Evaluation. This was based on:

- Orbital Performance factors (azimuth, inclination, flyover)
- Physical and Natural Environmental factors (environment, archeological, contiguous land, hurricane tidal surge, proximity to salt laden air, proximity to populated areas, explosive safety distances, launch vehicles size & class, transportation and seismic)

This method contains some quantifiable performance measures. However most of the topics are constant characteristics of the site and are not the performance topics of interest.

In the early 2000s a 50-year Cape Canaveral Spaceport Master Plan was explored by NASA Kennedy Space Center (KSC) in coordination with the USAF 45th Space Wing at the Cape Canaveral Air Force Station (CCAFS), and the Florida Space Authority. With the help of ZHA Consulting, of Orlando, Florida, the consortium explored markets, shared capabilities, and advanced architectural concepts in their work, which was made public in August of 2002.⁹

C. ASTWG/ARTWG

The Advanced Spaceport Technologies Working Group (ASTWG) published a *Baseline Report* in 2003 outlining a technological path towards low-cost, routine, access to space.¹⁰ The report provided a structured approach for evolving spaceports with ever-increasing capability.

After reaching consensus on the generalized spaceport environment, the government/industry/academia national ASTWG team also reached a consensus in defining what a *spaceport* is in terms of the following general functions:

1. Flight element operations
2. Payload element operations
3. Integrated Operations
4. Flight and ground Traffic Control and Safety Operations
5. Enabling Operations

The national ASTWG team created various capability roadmaps which defined a set of "technology pull" capabilities required for near-, mid-, and farther-term capabilities for advanced spaceports. These included:

1. Advanced servicing
2. Command, control and monitoring
3. Inspection and system verification

4. Transportation, handling, and assembly
5. Planning, documentation, analysis and learning
6. Cross-cutting spaceport architectures and capabilities

Another national group, similar to the ASTWG, addressed the independently-managed space ranges, such as the U.S. Eastern Range in Florida, and the Western Range in California. This group, the Advanced Range Technologies Working Group (or ARTWG), also identified areas to focus range technology advancement.¹¹ These included:

1. Tracking and surveillance
2. Telemetry and communication
3. Decision-making support
4. Weather measurement and forecasting
5. Cross-cutting Range architectures and capabilities

While the ASTWG/ARTWG baseline reports addressed the evolution of space flight ground operations and infrastructure, what is still needed is an achievable approach for evolving flight systems and spaceports together in a compatible manner. The inherent operability, supportability, maintainability, and safety/dependability of the total flight and ground system, are all highly dependent on the interaction of vehicle flight systems with ground systems, equipment, and facilities. The real challenge here will be the establishment of a structured, disciplined space flight test and certification methodology and a dedicated infrastructure to carry out this still unfulfilled critical function in the space transportation industry. Without it, investments in space flight service operators will remain a high risk proposition.

NASA KSC, the Air Force and the FAA initiated the Future Interagency Range and Spaceport Technologies (FIRST) program, which was in formulation during 2003 and 2004 to address these concerns. These types of technology investment efforts were surpassed in priority by the federal government partners in 2005, however, and the effort was abandoned.

IV. Available Data for Comparing Modern Spaceport Performance

Data is not readily available for many of the performance measures identified above. Most have not been formally organized for analysis purposes. Very few, if any, are monitored, managed and controlled in an operational sense for the purpose of space transportation performance improvement. However, readily available data can provide some indicators of performance and insight into the success of various Spaceports. Following are data at the author's ready access.^{12,13,14,15,16} Related data from other sources are requested by the authors for our continuing work in this area.

A. Throughput

Assessment of the "Capacity" of spaceports has not been addressed to date. Many launch pads are infrequently used. Therefore the Capacity of most spaceports is many times the actual "throughput". Therefore assessing the "Load Factor" becomes problematic. However, actual launch "throughput" is regularly tracked and assessed by the authors and is presented below for Calendar Year 2009 and for the past decade:

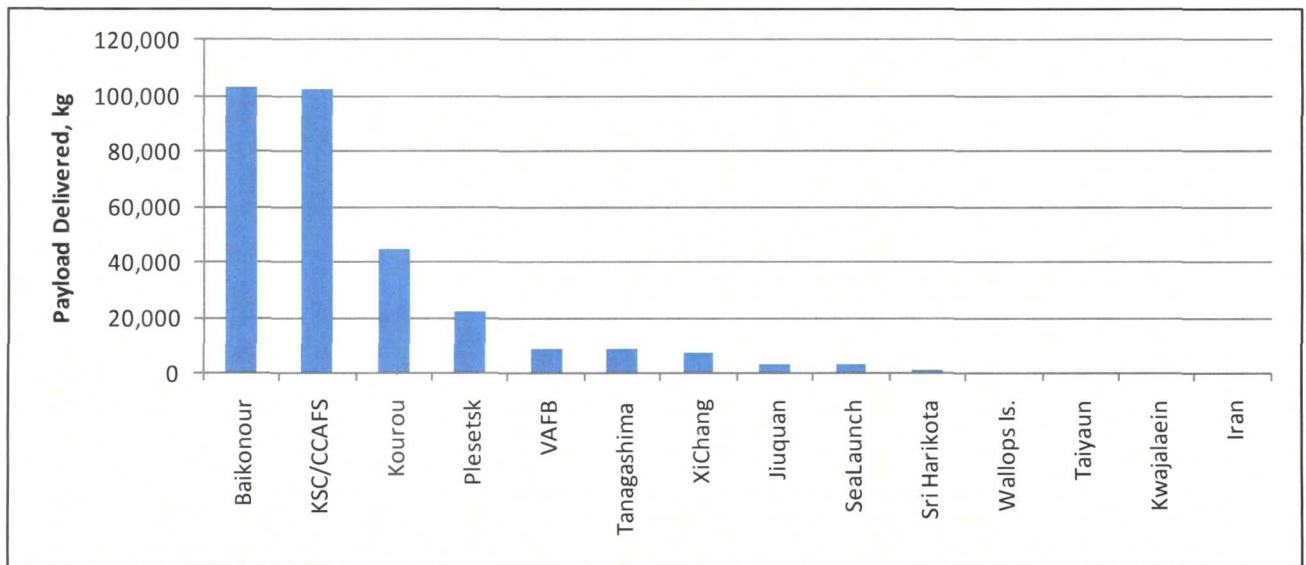


Figure 4: Calendar year 2009 distribution of total payload delivered by launch site/range¹⁷

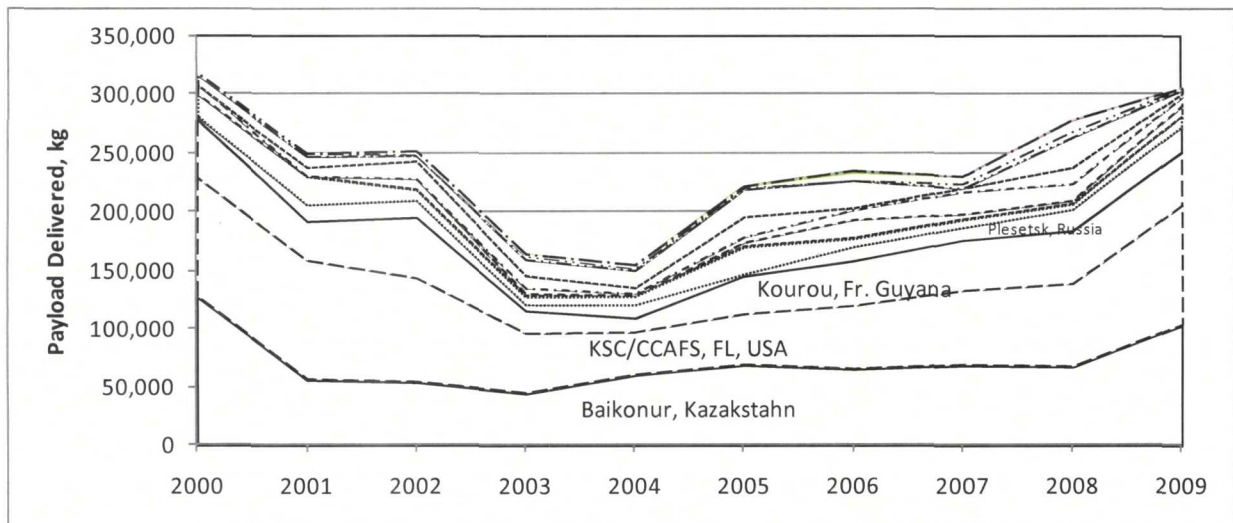


Figure 5: Worldwide Ten-Year Payload Delivery Trend by Launch Site/Range

B. Availability/Responsiveness

Scheduling data is widely dispersed and needs to be collected and assimilated with better discipline. Data is invited in the areas of:

- On-Time Ratio (Launches):
- Range Reconfigure Time (Hours):
- Pad/Facility Assignment Schedule (Days):
- Vehicle Assessment Schedule (Days):

Delay data also requires assessments and analyses. Data is invited in the areas of:

- Space Flight Delays (Occurrences)
- Space Flight Delay Impact (Days)
- Space Flight Operator Delays (Occurrences)
- Space Flight Operator Delay Impact (Days)
- Customer Delays (Occurrences)

- Customer Delay Impact (Days)
- Spaceport Equipment/Service Delays (Occurrences)
- Spaceport Equipment/Service Delay Impact (Days)
- Preemption Delay (Occurrences)
- Preemption Delay (Days)
- Flight Path/Airspace Availability (Hours/ year)

C. Safety

Relevant safety data is primarily collected by vehicle and needs to be reanalyzed by launch or landing location. The authors assessed the space flight track record for orbital launches and entries occurring around the world from the calendar years 2000 through 2009. Data in this section is derived from both the classical and Bayesian methods for examining space flight success records.¹⁸

For human space flight launches, the data in Figure 6 through Figure 8 can lead to initial observations:

- All Space Shuttle launches take place from Kennedy Space Center (KSC). This location, therefore, demonstrates the safest combination of vehicle, operator, and spaceport systems (equipment and workforces), when using a Bayesian process for determining the probability of success.
- The manned Soyuz vehicles operate from Baikonur Cosmodrome in central Kazakhstan. This vehicle/cosmodrome combination presents a very similar, but slightly lower probability of success to date than Kennedy Space Center, due to a 30% lower number of total human space flights successes.
- The Long March 2F launch vehicle/Zhengzhou spacecraft combination operates from Jiuquan Satellite Launch Center in China. To date, a 100% success rate has been demonstrated, so far indicating a safe approach for vehicle, personnel and management systems. The number of successes amounts to only three, however, and if one applies a Bayesian probability (to adjust for the low number of launches to date) then the Long March 2F/Zhengzhou probability of success will remain less than KSC until they reach 65+ launches without a failure. This may take a decade or more to accomplish at the current flight rate.

In all cases, both of the probability assessment methods (i.e., both classical and Bayesian) need to be considered together and used with judgment as space flight systems gain launch experience to earn the confidence of various stakeholders—including spaceports.

Launches	Tries (n)	Successes (k)	Classical Demonstrated Probability of Success, P_s	Bayesian Demonstrated Probability of Success, P_s
			(k/n)	(k+1/n+2)
Space Shuttle Vehicle	129	128	0.9922	0.9847
Soyuz U/FG Launch Veh (All manned launches)	104	103	0.9904	0.9811
Soyuz FG manned Launches	20	20	1.0000	0.9545
Long March 2F/Manned	3	3	1.0000	0.8000

Figure 6: Success Probability of Human Launch & Spaceports Systems

Launch Site (Spaceport/Range)	Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Grand Total (n)	Ten-Year Launch Successes (k)	Ten-Year Cumulative Classical_Ps (k/n)	Ten-Year Cumulative Bayesian_Ps (k+1)/(n+2)
Kennedy Space Center, FL	USA	5	6	5	1*	0	1	3	3	4	5	33	33	1.00000	0.97143
Cape Canaveral AFS, FL	USA	14	10	9	17	13	6	7	10	3	11	100	98	0.98000	0.97059
KSC/Eastern Range	USA	19	16	14	18	13	7	10	13	7	16	133	131	0.98496	0.97778
Baikonour	Khazakistan	30	16	15	14	17	19	17	20	19	24	191	185	0.96859	0.96373
Kourou	Fr. Guiana	12	8	12	4	3	5	5	6	6	7	68	66	0.97059	0.95714
Ji Quan	China	0	1	2	2	2	4	1	1	3	2	18	18	1.00000	0.95000
Vandenberg AFB, CA	USA	8	5	3	5	3	5	6	4	4	6	49	47	0.95918	0.94118
Xi Chang	China	4	0	0	3	3	1	3	6	4	2	26	25	0.96154	0.92857
Tanagashima	Japan	0	1	3	2	0	1	4	2	1	3	17	16	0.94118	0.89474
Plesetsk	Russia	5	6	10	7	5	6	5	5	6	8	63	56	0.88889	0.87692
SeaLaunch System	(Pacific Ocean)	3	2	1	3	3	4	5	1	5	1	28	25	0.89286	0.86667
Taiyuan	China	1	0	3	2	3	0	2	3	4	2	20	18	0.90000	0.86364
Satish Dhawan Space Center	India	0	2	1	2	1	1	1	3	3	2	16	14	0.87500	0.83333
Wallops Island, VA	USA	0	0	0	0	0	0	1	1	0	1	3	3	1.00000	0.80000
Dombrovsky	Russia	0	0	0	0	0	0	1	1	1	0	3	3	1.00000	0.80000
Svobodny	Russia	1	1	0	0	0	0	1	0	0	0	3	3	1.00000	0.80000
Kagoshima	Japan	1	0	0	1	0	1	2	0	0	0	5	4	0.80000	0.71429
Kodiak Launch Complex, AK	USA	0	1	0	0	0	0	0	0	0	0	1	1	1.00000	0.66667
Kapustin Yar	Russia	0	0	0	0	0	0	0	0	1	0	1	1	1.00000	0.66667
Kwajalein	Marshall Is.	1	0	0	0	0	0	1	1	4	1	8	5	0.62500	0.60000
Palamchina	Israel	0	0	1	0	1	0	0	1	0	0	3	2	0.66667	0.60000
Barents Sea (sub launch)	Russia	0	0	0	0	0	1	1	0	0	0	2	1	0.50000	0.50000
Alcantara	Brazil	0	0	0	0	0	0	0	0	0	0	0	0	-	0.50000
Naro Space Center	S. Korea	0	0	0	0	0	0	0	0	0	1	1	0	0.00000	0.33333
Musudan-ri	N. Korea	0	0	0	0	0	0	0	0	0	1	1	0	0.00000	0.33333
Semnan	Iran	0	0	0	0	0	0	0	0	0	1	1	0	0.00000	0.33333
Global Grand Total		85	59	65	63	54	55	66	68	68	78	661	624	0.94402	0.94268

* Counts successful deliveries to correct orbit. Failure on entry of STS-107, Columbia.

Figure 7—Worldwide Spaceport Launch site success record (2000-2009)

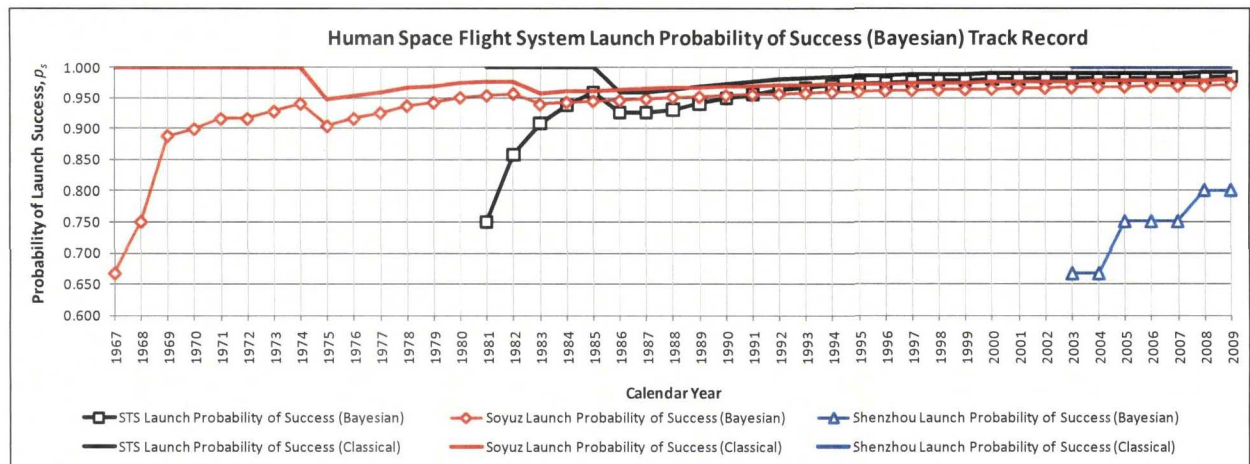


Figure 8: Human Space Flight Launch Success Record (for Existing Systems)

Similarly, for human re-entries and landings, data in Figure 9 and Figure 10 can lead to these initial observations:

- Orbiter landings are managed by a common flight organization and most occurred at Kennedy Space Center (KSC). However, landings at White Sands and Edwards AFB also were frequent, with KSC recovery teams deployed to those contingency locations. These locations similarly demonstrate the safest combination of vehicle, personnel and management systems, when using a Bayesian method to determine the probability of success.

- The Soyuz vehicles land at various locations within a large landing zone in northern and eastern Kazakhstan. This combination of vehicle/cosmodrome presents a very good probability of success to date; again, slightly less than the Kennedy Space Center, White Sands, Edwards combination, due to 30% fewer entries and entry successes. The method of entry has also involved several “close call” entries, nonetheless avoiding fatalities.
- The Zhengzhou spacecraft land in China's northern grasslands at Siziwangqi, Inner Mongolia. To date, a 100% success rate has been demonstrated, so far indicating a safe approach for vehicle, personnel, and management systems. If one applies a Bayesian probability (to adjust for the low number of entries to date), then the probability of success will remain less than KSC until they reach 65+ landings without a failure. This may take a decade or more to accomplish. Therefore, both probabilities need to be considered together and used with judgment.

Again, both of the probability assessments methods (classical and Bayesian) need to be considered together and used with judgment as space flight systems gain re-entry and landing experience to earn the confidence of various stakeholders—including spaceports.

Entries	Tries (n)	Successes (k)	Classical	Bayesian
			Demonstrated Probability of Success, P_s (k/n)	Demonstrated Probability of Success, P_s (k+1/n+2)
Shuttle Orbiter	128	127	0.9922	0.9846
Soyuz	100	98	0.9800	0.9706
(All manned spacecraft versions)				
Shenzhou	3	3	1.0000	0.8000

Figure 9: Success Probability of Human Reentry, Landing & Spaceports Systems

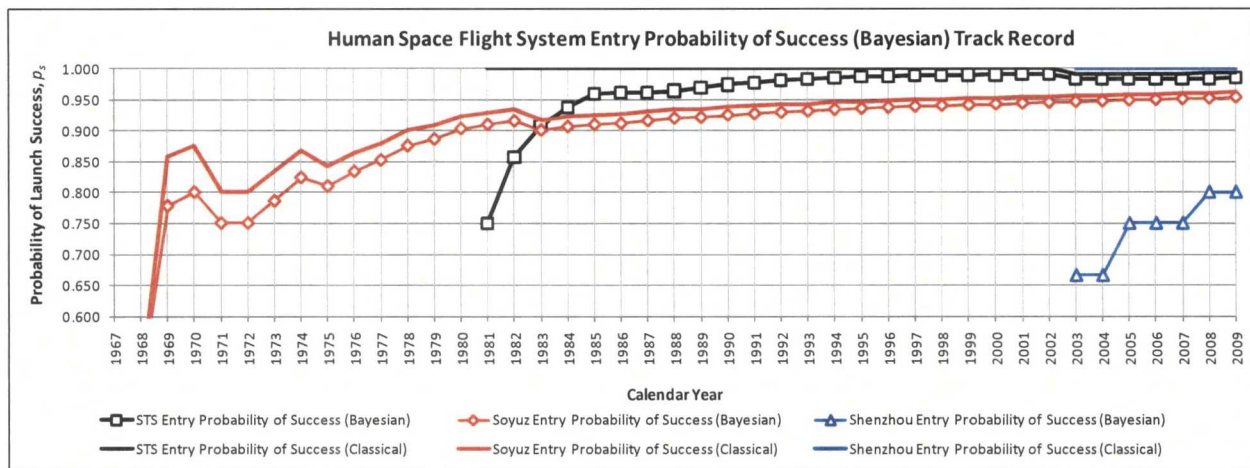


Figure 10: Human Space Flight Entry Success Record (for Existing Systems)

D. Financial/Business Case Sensitivity

Financial data, which is so important to space flight service operators in making a decision regarding a launch site, remains challenging to obtain and analyze due to competitive sensitivities. However, other successful transportation sectors in the economy form industry groups, such as the Air Transport Association (ATA), to overcome such issues for the common benefit of the industry at-large. The authors invite data to be submitted for future updates to this paper and topic.

E. Energy Efficiency/Environmental Sustainability

Spaceports are substantial users of energy, commodities, land area and are major employers. Some of their requirements make efficient management practices challenging. (Example: There is little opportunity for electrical load shedding during critical launch operations.) However, the bulk of the facilities and operations are more commercial and industrial in nature. These provide numerous opportunities for incorporating the type of sustainable features which will provide the "triple bottom line" to people, planet and profits. The extensive explosive clear zones and launch danger areas typically represent large areas of undeveloped land which are successfully used as wildlife preserves and habitat for threatened and endangered species. New launch site development techniques developed by the authors can limit environmental disturbance and increase high value habitat for certain species¹⁹. Performance indicators in this area include:

- Energy Launch Efficiency (joules/pound to LEO)
- Greenhouse Gases (GHG pounds/pound to LEO): Consider Direct, indirect and Optional GHG emission categories.
- Water Consumption (gallons/pound to LEO)
- Habitat Ratio (acres of T&E habitat / total acres)
- Sustainability (waste pounds/pound to LEO)
- LEED Ration (area of LEED certified development / total developed area)

V. Summary

Spaceports currently serve a limited role in the development of our Nation's commercial space transportation. It is vital to our Nation that they are developed in a manner which is responsive to the needs of all their stakeholders in order to elevate space transportation's importance and relevance to our overall economy and global stewardship. Most Spaceports, their operator community, and their flying customers, now experience substantial underutilized capacity, unresponsive schedules, excellent safety, indeterminable financials, and are generally lacking investments in sustainable practices. The importance of bringing our Nation's spaceports into the 21st century cannot be overstated. By so doing, the space transportation industry can grow beyond the relatively smaller-scale 20th century operations, still in existence today, into a more significant contributor of the global economy, enabling space transportation for all.

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